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(54) **METHOD OF DETECTING THE STATE OF WEAR OF AN ELECTRIC ACTUATOR**

(57) A method for detecting the status of wear of an electric actuator, wherein said electric actuator comprises an electric motor having a drive shaft, a load suitable for being driven in translation by the electric motor along a translation axis, and a transmission system interposed between the electric motor and the load and suitable for converting the rotation of the drive shaft into a translation of the load, comprises the steps of:
a) axially locking the load in the direction of the translation axis,

b) applying a first test torque to the drive shaft in a first direction of rotation;
c) removing the first test torque;
d) detecting a first angular position of the drive shaft;
e) applying a second test torque to the shaft in a second direction of rotation opposite to the first;
f) removing the second test torque;
g) detecting a second angular position of the drive shaft;
h) measuring the difference between the first angular position and the second angular position.

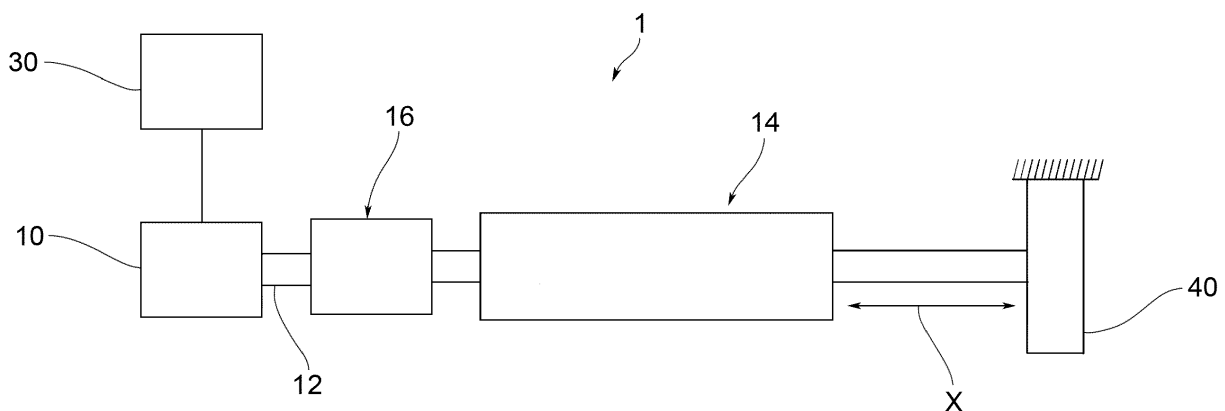


FIG.1

Description

[0001] The present invention refers to a method for detecting the status of wear of an electric actuator, and an electric actuator comprising means suitable for detecting its own status of wear.

[0002] The electric actuator, whose status of wear is to be detected, comprises an electric motor having a drive shaft, a load suitable for being driven in translation by the electric motor along a translation axis, and a transmission system interposed between the electric motor and the load and suitable for converting the rotation of the drive shaft into a translation of the load.

[0003] For example, the electric actuator is an electric cylinder.

[0004] The present invention aims to provide a method for automatically detecting the status of wear of an electric actuator, in particular for conducting predictive diagnostic analyses on the operation of the electric actuator.

[0005] This purpose is achieved with a method for detecting the status of wear of an electric actuator according to claim 1, with a control unit of an electric actuator according to claim 5, with a method for measuring the play in an electric actuator according to claim 8, with a computer program according to claim 11, and with an electric actuator according to claim 12.

[0006] The dependent claims describe preferred embodiments of the invention.

[0007] The features and advantages of the invention will become clear from the description given below of preferred embodiments, given solely as non-limiting examples in reference to the enclosed figures, wherein:

[0008] - figure 1 is a schematic representation of an electric actuator according to the invention;

[0009] - figure 2 shows an example of an embodiment of the electric actuator according to the invention;

[0010] - figure 3 is a graphic showing the application of test torques to the electric actuator and measurement of the play in the actuator in millimeters.

[0011] In these drawings, the number 1 refers to an electric actuator as a whole, according to the invention.

[0012] In a general embodiment, it is known that electric actuator 1 comprises an electric motor 10 having a drive shaft 12, a load 14 suitable for being driven in translation by electric motor 10 along a translation axis X, and a transmission system 16 interposed between electric motor 10 and load 14 and suitable for converting the rotation of drive shaft 12 into a translation of load 14.

[0013] The Applicant has discovered that the detection and measurement of play introduced by transmission system 16 can be used for diagnostic purposes to conduct predictive analyses on the proper operation of actuator 1, that is, to predict when the actuator must be replaced or possibly repaired before the actuator breaks or before an unacceptable deterioration of performance.

[0014] In one embodiment shown in figure 2, electric actuator 1 is an electric cylinder. The electric cylinder comprises electric motor 10, preferably a torque-controllable motor, suitable for controlling the rotation of a drive shaft 12.

[0015] In one embodiment, a reduction gear is placed between motor 10 and drive shaft 12.

[0016] In this case, load 14 driven in translation is represented by a rod 18 sliding in sleeve 20 of the electric cylinder.

[0017] In one embodiment, transmission system 16 that converts the rotation of the drive shaft into a translation of the rod comprises a ball screw system 162.

[0018] Screw 162 can be housed inside rod 18, which in this case is hollow.

[0019] The balls are contained in lead nut 164 integral to rod 18, and therefore also slides inside the section formed by sleeve 20 of the cylinder.

[0020] In one embodiment, electric actuator 1 is provided with a device for detecting the angular position of the drive shaft, for example an encoder. This device can be incorporated directly into the electric motor.

[0021] Electric actuator 1 comprises a control unit 30 suitable for controlling electric motor 10. Control unit 30 is provided with a computer program implementing the method for detecting the status of wear of the electric actuator which will be described below.

[0022] Electric actuator 1 further comprises an axial locking device 40 that is activatable to lock load 14 at least axially in the direction of the axis of translation X.

[0023] In a preferred embodiment for detecting the total backlash of the electric actuator, axial locking device 40 is configured to allow load 14 to be free to rotate about the axis of translation X.

[0024] For example, axial locking device 40 comprises a joint provided with skids that allow rod 18 only to undergo rotation and not translation.

[0025] In some embodiments or in some applications where the load does not have the possibility of rotating, it is possible to apply the method for detecting the status of wear described above to detect--if not the axial play due to the wear of the skids--the axial play of the rest of the transmission system, particularly the play introduced by the ball screw and bearings.

[0026] It must be noted that axial locking device 40 does not necessarily need to be built into or integral to electric actuator 1. In particular, axial locking device 40 could be supplied as an accessory if the wear detection method is to be applied to an electric actuator already being used in the field.

[0027] Similarly, the computer program implementing the wear detection method does not necessarily need to be preloaded into the memory of control unit 30, but can be installed on the control unit of a conventional electric actuator.

[0028] According to a feature of the invention, the method for detecting the wear of an electric actuator comprises the following steps.

[0029] Load 14 is locked axially in the direction of the axis of translation X.

[0030] In a preferred embodiment, the load is left free to rotate about the axis of translation X.

[0031] By means of electric motor 10, a first test torque C1 is applied to drive shaft 12 in a first direction of rotation, such as the clockwise direction.

[0032] First test torque C1 must be at least enough to overcome the internal friction of electric actuator 1.

[0033] First test torque C1 is then removed. In one embodiment, first test torque C1 is decreased linearly, or according to some other suitable law, to avoid any elastic inertia of the system. In some cases it may be appropriate to leave a residual torque to avoid elastic returns of the system.

[0034] A first angular position of drive shaft 12 is detected, i.e. the position of drive shaft 12 upon removal of first test torque C1 or once the predetermined residual torque is reached.

[0035] At this point a second test torque C2 is applied to drive shaft 12 by means of electric motor 10 in a second direction of rotation opposite to the first, such as the counterclockwise direction. In one embodiment, second test torque C2 is equal to first test torque C2 in absolute value. In other embodiments, however, second test torque C2 could also be different from first test torque C1, for example based on the load conditions of the actuator. For example, a different torque could be necessary if the cylinder is installed in a vertical position, in which case the torque required to make the rod come out must also overcome the weight of the lead nut and lead nut holder, whereas the torque in the opposite direction needs to be less since gravity is assisting.

[0036] Second test torque C2 is then removed or reduced to the predetermined residual value.

[0037] A second angular position of drive shaft 12 is then detected.

[0038] Here again, second test torque C2 can be reduced linearly or according to a different and more favorable law.

[0039] At this point, the difference D between the first angular position and the second angular position, or between a first position value P1 obtained from the first angular position and a second position value P2 obtained from the second angular position, is measured (Figure 3).

[0040] For example, the first and second angular positions can be converted into a linear quantity, such as millimeters, before calculating the difference.

[0041] Alternatively, the conversion to length can be done after finding the difference between the two angular positions.

[0042] For example, in the case of an electric cylinder, the conversion from encoder steps to millimeters is calculated by the gear ratio and screw pitch of the cylinder.

[0043] The value given by the difference between the two positions is the play or backlash of the electric actuator.

[0044] A numerical example of the backlash detection method according to the invention applied to an electric cylinder is described in figure 3.

[0045] After locking the rod axially, but not angularly, a torque C1 of 0.45 Nm is applied to the actuator in the clockwise direction.

[0046] The torque is dropped in a non-instantaneous way, with a step at 0.045 Nm.

[0047] Lastly, the torque is set to 0 Nm.

[0048] The angular position of the shaft is detected and converted into millimeters (Position P1).

[0049] A torque of -0.45 Nm is then applied to the actuator in counterclockwise direction C2.

[0050] The torque is dropped in a non-instantaneous way, with a step at -0.045 Nm.

[0051] Lastly, the torque is set to 0 Nm.

[0052] The angular position of the shaft is detected and converted into millimeters (Position P2).

[0053] The difference D between first position P1 and second position P2 is calculated to determine the backlash:

$$\text{backlash} = |\text{Position P1} - \text{Position P2}|$$

[0054] The test can be repeated with various torque values to simulate the behavior of the actuator.

[0055] According to a feature of the invention, a control unit 30 for controlling a programmable electric actuator is provided to implement the wear detection method described above.

[0056] Control unit 30 is then configured to:

- control the electric motor to apply a first test torque C1 to the drive shaft in a first direction of rotation;
- control the electric motor to remove the first test torque C1 or reduce the first test torque C1 to a predetermined residual value;

- receive, from a position sensor, a first datum representative of a first angular position of the drive shaft;
- control the electric motor to apply a second test torque C2 to the drive shaft in a second direction of rotation;
- control the electric motor to remove second test torque C2 or reduce the second test torque to said predetermined residual value;
- 5 - receive, from said position sensor, a second datum representative of a second angular position of the drive shaft;
- measure the difference between said first datum and said second datum or between a first position value P1 obtained from the first datum and a second position value P2 obtained from the second datum.

[0057] In one embodiment, second test torque C2 is equal to first test torque C1 in absolute value.

[0058] In one embodiment, the first and second test torques are decreased linearly or according to a different and more favorable law that minimizes the elastic returns of the transmission system.

[0059] The subject matter of the invention also refers to a computer program running on a control unit of an electric actuator and comprising portions of code suitable for carrying out the functions described above on the control unit.

[0060] In one embodiment, the computer program is suitable for:

- controlling the electric motor to apply a first test torque to the drive shaft in a first direction of rotation;
- controlling the electric motor to remove the first test torque or reduce the first test torque to a predetermined residual value;
- storing a first datum representative of a first angular position of the drive shaft assumed when removing the first test torque or upon reaching the residual torque value;
- 20 - controlling the electric motor to apply a second test torque to the drive shaft in a second direction of rotation;
- controlling the electric motor to remove the second test torque or reduce the second test torque to said predetermined residual value;
- storing a second datum representative of a second angular position of the drive shaft assumed when the second test torque is removed or upon reaching the residual torque value;
- 25 - measuring the difference between said first datum and said second datum or between a first position value obtained from the first datum and a second position value obtained from the second datum.

[0061] In one embodiment, the second test torque is equal to the first test torque in absolute value.

[0062] According to a feature of the invention, an electric actuator comprising an electric torque-controllable motor with a drive shaft, a load suitable for being driven in translation by the electric motor along a translation axis, a transmission system interposed between the electric motor and the load and suitable for converting the rotation of the drive shaft into a translation of the load, an angular position sensor suitable for detecting the angular position of the drive shaft, and a control unit for controlling the programmable electric motor as described above and operatively connected to the position sensor, is provided.

[0063] It must be stressed that the method for detecting and calculating the play of the electric actuator is completely automated. The test process for calculating the play is very fast to carry out and can be applied advantageously to the electric motor when the electric actuator is paused, such as between two movements of the load.

[0064] In order to satisfy contingent requirements, a person skilled in the art could make modifications, adaptations, and substitutions of parts with functionally equivalent ones to the embodiments of the invention, without exceeding the scope of the following claims. Each feature described as belonging to a possible embodiment may be implemented independently of the other described embodiments.

Claims

1. Method for detecting the status of wear of an electric actuator, wherein said electric actuator comprises an electric motor having a drive shaft, a load suitable for being driven in translation by the electric motor along a translation axis, and a transmission system interposed between the electric motor and the load and suitable for converting the rotation of the drive shaft into a translation of the load, comprising the steps of:

- a) axially locking the load in the direction of the translation axis,
- b) applying, by means of the electric motor, a first test torque to the drive shaft in a first direction of rotation;
- c) removing the first test torque or reducing the first test torque to a predetermined residual value;
- 55 d) detecting a first angular position of the drive shaft;
- e) applying, by means of the electric motor, a second test torque to the drive shaft in a second direction of rotation opposite to the first;
- f) removing the second test torque or reducing the second test torque to said predetermined residual value;

- g) detecting a second angular position of the drive shaft;
- h) measuring the difference between the first angular position and the second angular position or between a first position value obtained from the first angular position and a second position value obtained from the second angular position.

2. Method according to claim 1, wherein the axially locked load is left free to rotate about the translation axis.
3. Method according to claim 1 or 2, wherein the second test torque is equal in absolute value to the first test torque.
4. Method according to claim 1, wherein, in steps c) and f) the test torque is made to decrease in a linear manner or other law suitable for minimizing the elastic returns of the transmission system.
5. Control unit of an electric actuator, wherein said electric actuator comprises an electric motor having a drive shaft, a load suitable for being driven in translation by the electric motor along a translation axis, and a transmission system interposed between the electric motor and the load and suitable for converting the rotation of the drive shaft into a translation of the load, the control unit being programmed for:
 - controlling the electric motor to apply a first test torque to the drive shaft in a first direction of rotation;
 - controlling the electric motor to remove the first test torque or reduce the first test torque to a predetermined residual value;
 - receiving, from a position sensor, a first datum representative of a first angular position of the drive shaft;
 - controlling the electric motor to apply a second test torque to the drive shaft in a second direction of rotation;
 - controlling the electric motor to remove the second test torque or reduce the second test torque to said predetermined residual value;
 - receiving, from said position sensor, a second datum representative of a second angular position of the drive shaft;
 - measuring the difference between said first datum and said second datum or between a first position value obtained from the first datum and a second position value obtained from the second datum.
6. Control unit according to the preceding claim, wherein said second test torque is equal in absolute value to the first test torque.
7. Control unit according to claim 5 or 6, wherein the first and the second test torque are made to decrease linearly or according to another law suitable for minimizing the elastic returns of the transmission system.
8. Method of measuring play in an electric actuator, wherein said electric actuator comprises an electric motor having a drive shaft, a load suitable for being driven in translation by the electric motor along a translation axis, and a transmission system interposed between the electric motor and the load and suitable for converting the rotation of the drive shaft into a translation of the load, comprising the steps of:
 - controlling the electric motor to apply a first test torque to the drive shaft in a first direction of rotation;
 - controlling the electric motor to remove the first test torque or reduce the first test torque to a predetermined residual value;
 - storing a first datum representative of a first angular position of the drive shaft assumed when removing the first test torque or upon reaching the residual torque value;
 - controlling the electric motor to apply a second test torque to the drive shaft in a second direction of rotation;
 - controlling the electric motor to remove the second test torque or reduce the second test torque to said predetermined residual value;
 - storing a second datum representative of a second angular position of the drive shaft assumed when the second test torque is removed or upon reaching the residual torque value;
 - measuring the difference between said first datum and said second datum or between a first position value obtained from the first datum and a second position value obtained from the second datum.
9. Method according to the preceding claim, wherein said second test torque is equal in absolute value to the first test torque.
10. Method according to the preceding claim, wherein the first and the second test torque are made to decrease linearly or according to another law suitable for minimizing the elastic returns of the system.

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11. Computer program executable on a control unit of an electric actuator and comprising code portions suitable for implementing the method according to any one of claims 8-10.

5 12. Electric actuator, comprising an electric torque-controllable motor and having a drive shaft, a load suitable for being driven in translation by the electric motor along a translation axis, a transmission system interposed between the electric motor and the load and suitable for converting the rotation of the drive shaft into a load translation, an angular position sensor suitable for detecting the angular position of the drive shaft, and a control unit of the electric motor according to any one of claims 5-7 and operatively connected to the position sensor.

10 13. Electric actuator according to the preceding claim, wherein the load is a rod slidable in a cylinder, and wherein the transmission system comprises a ball screw.

14. Electric actuator according to claim 12 or 13, further comprising an axial locking device which is activatable for axially locking the load in the direction of the translation axis.

15 15. Electric actuator according to claim 14, wherein the axial locking device is configured to leave the load free to rotate about the translation axis.

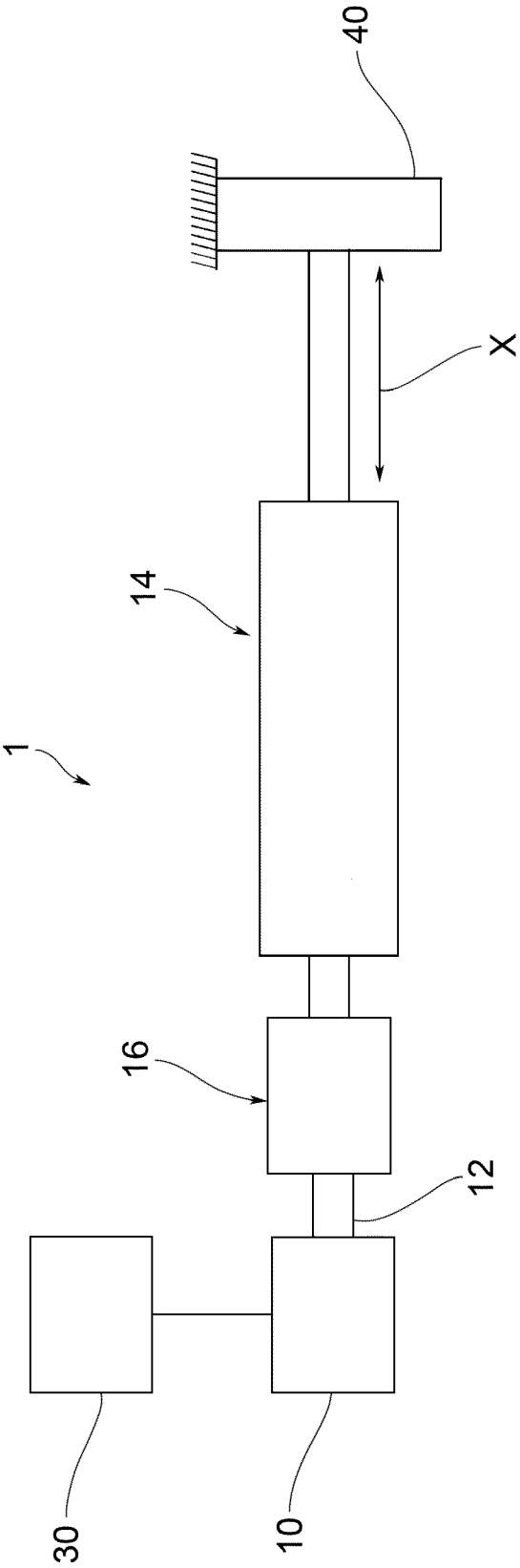


FIG.1

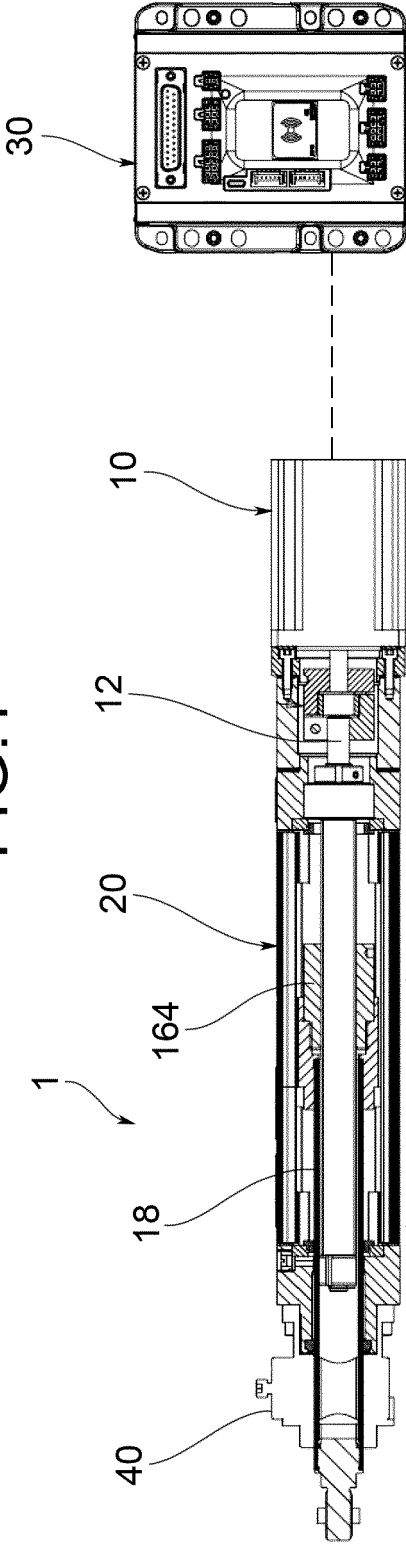


FIG.2

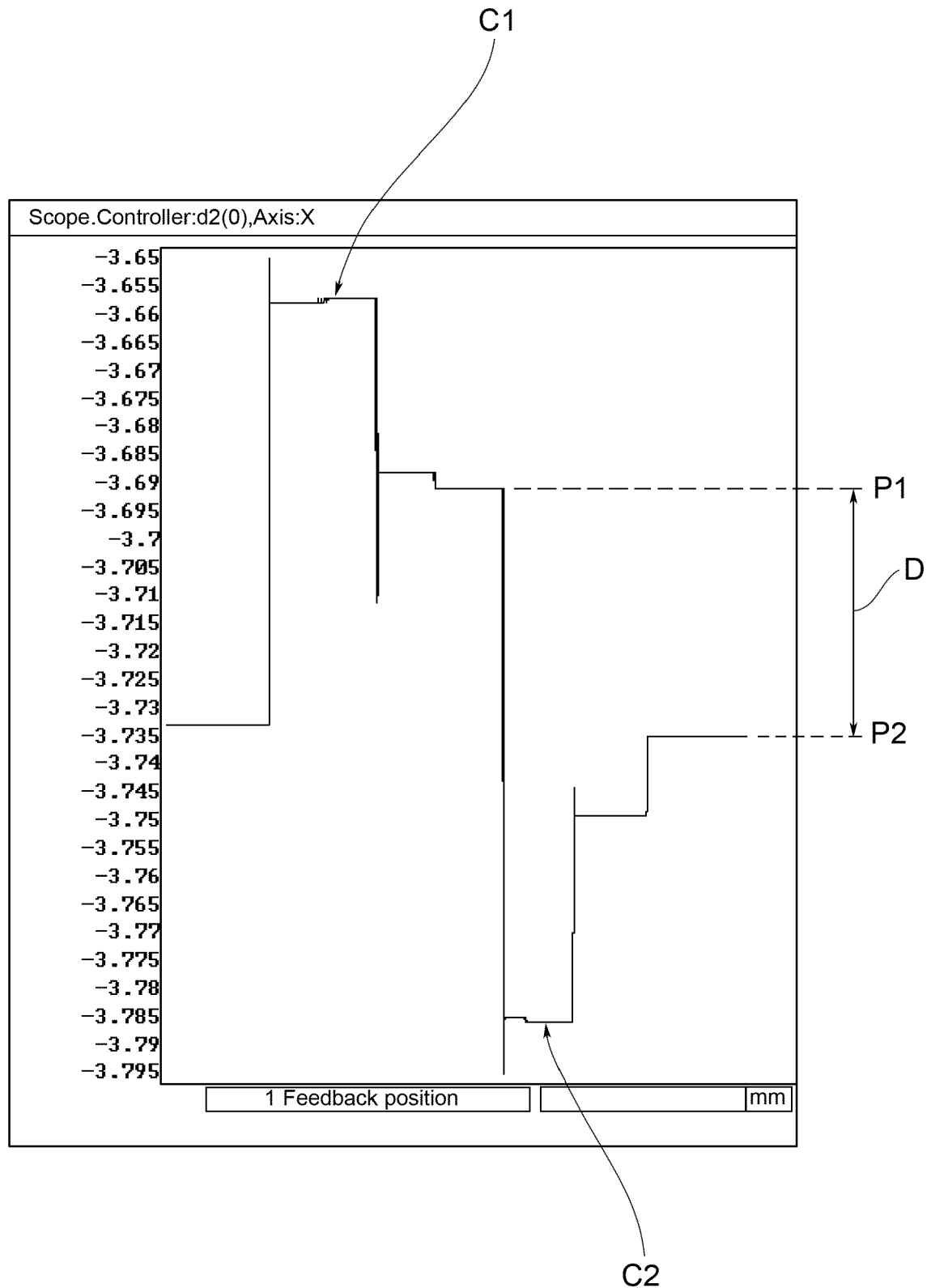


FIG.3



EUROPEAN SEARCH REPORT

Application Number
EP 20 16 7226

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DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
A	WO 2010/134884 A1 (IND SERVICE APPLIC ISA AB [SE]; PERNESTAAL KJELL [SE]) 25 November 2010 (2010-11-25) * figures 1-7 * * claims 8-15 *	1-15	INV. F16H57/01 G01M13/00
A	WO 2008/007058 A2 (ROTORK CONTROL LTD [GB]; SANDERS PETER GEORGE [GB] ET AL.) 17 January 2008 (2008-01-17) * figures 1-10 * * page 11, line 5 - page 11, line 15 *	1-15	
A	KR 100 957 952 B1 (SEBU ELECTRIC & MACHINERY CO L) 13 May 2010 (2010-05-13) * figures 1-9 * * claim 1 * * paragraphs [0010], [0024], [0026], [0063] *	1-15	
A	FR 3 050 523 A1 (SAGEM DEFENSE SECURITE [FR]) 27 October 2017 (2017-10-27) * figures 1-10 * * claim 1 *	1-15	TECHNICAL FIELDS SEARCHED (IPC)
A	US 2019/063568 A1 (LASKOVY ANDREW M [US] ET AL) 28 February 2019 (2019-02-28) * figures 1-5 * * paragraphs [0008], [0026] * * claim 19 *	1-15	G01M F16H
The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 25 August 2020	Examiner Gubovits, János
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document	

EPO FORM 1503 03.82 (P04C01)

**ANNEX TO THE EUROPEAN SEARCH REPORT
ON EUROPEAN PATENT APPLICATION NO.**

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5 This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
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25-08-2020

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2010134884 A1	25-11-2010	EP 2433086 A1	28-03-2012
		SE 0900686 A1	21-11-2010
		US 2012067139 A1	22-03-2012
		WO 2010134884 A1	25-11-2010
WO 2008007058 A2	17-01-2008	BR PI0714375 A2	05-03-2013
		CN 101506747 A	12-08-2009
		EP 2038713 A2	25-03-2009
		GB 2440040 A	16-01-2008
		JP 5700271 B2	15-04-2015
		JP 2009543004 A	03-12-2009
		KR 20090029282 A	20-03-2009
		NO 341231 B1	18-09-2017
		RU 2009104084 A	20-08-2010
		TW 200817613 A	16-04-2008
		US 2009230338 A1	17-09-2009
		WO 2008007058 A2	17-01-2008
KR 100957952 B1	13-05-2010	CN 1525094 A	01-09-2004
		KR 20040076194 A	31-08-2004
		TW I223042 B	01-11-2004
FR 3050523 A1	27-10-2017	CN 109073374 A	21-12-2018
		EP 3446067 A1	27-02-2019
		FR 3050523 A1	27-10-2017
		US 2019144135 A1	16-05-2019
		WO 2017182593 A1	26-10-2017
US 2019063568 A1	28-02-2019	NONE	